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(54) **TURBINE OF A TURBOMACHINE**

(75) Inventors: **Paul Kendall Smith**, Simpsonville, SC (US); **Gunnar Leif Siden**, Greenville, SC (US); **Craig Allen Bielek**, Greenville, SC (US); **Thomas William Vandeputte**, Scotia, NY (US)

(73) Assignee: **GENERAL ELECTRIC COMPANY**, Schenectady, NY (US)

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CPC F05D 2250/30; F05D 2240/125; F05D 2240/307; F01D 5/141; F01D 5/142; F01D 5/145
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See application file for complete search history.

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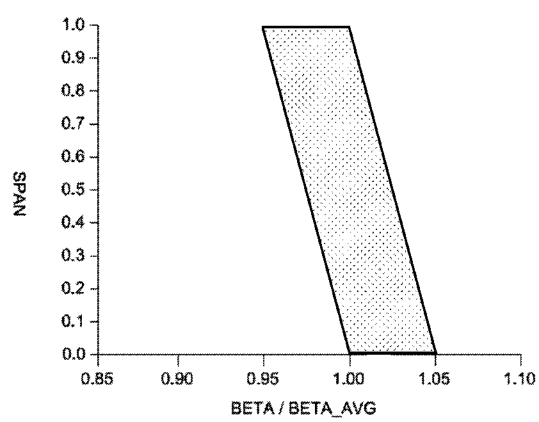
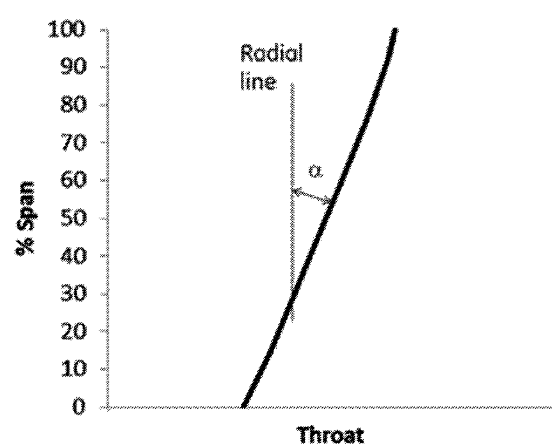
Primary Examiner — Dwayne J White
Assistant Examiner — Joshua R Beebe
(74) *Attorney, Agent, or Firm* — Dority & Manning, PA

(57) **ABSTRACT**

A turbine of a turbomachine is provided and includes opposing endwalls defining a pathway for a fluid flow and a plurality of interleaved blade stages and nozzle stages arranged axially along the pathway. The plurality of the blade stages includes a last blade stage at a downstream end of the pathway and a next-to-last blade stage upstream from the last blade stage. The plurality of the nozzle stages includes a last nozzle stage between the last blade stage and the next-to-last blade stage and a next-to-last nozzle stage upstream from the next-to-last blade stage. At least one of the next-to-last blade stage and the next-to-last nozzle stage includes aerodynamic elements configured to interact with the fluid flow and to define a throat distribution producing a tip strong pressure profile in the fluid flow.

19 Claims, 3 Drawing Sheets





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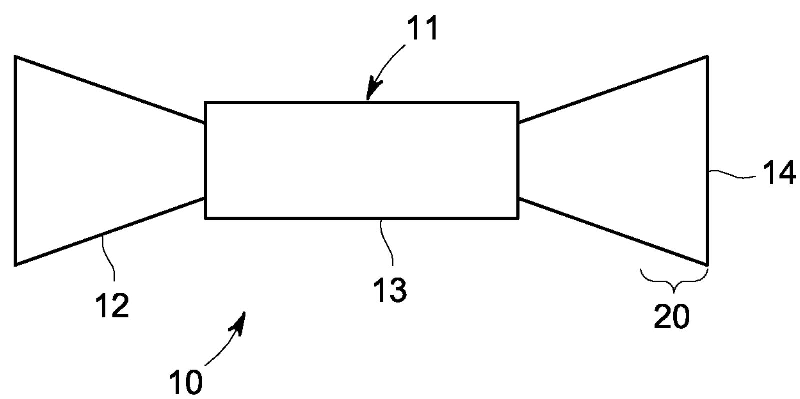

FIG. 1

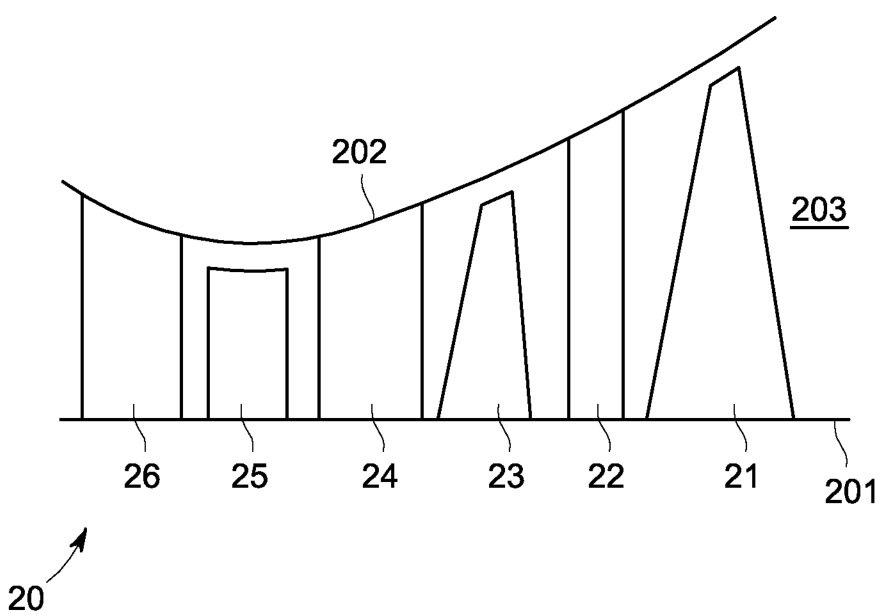

FIG. 2

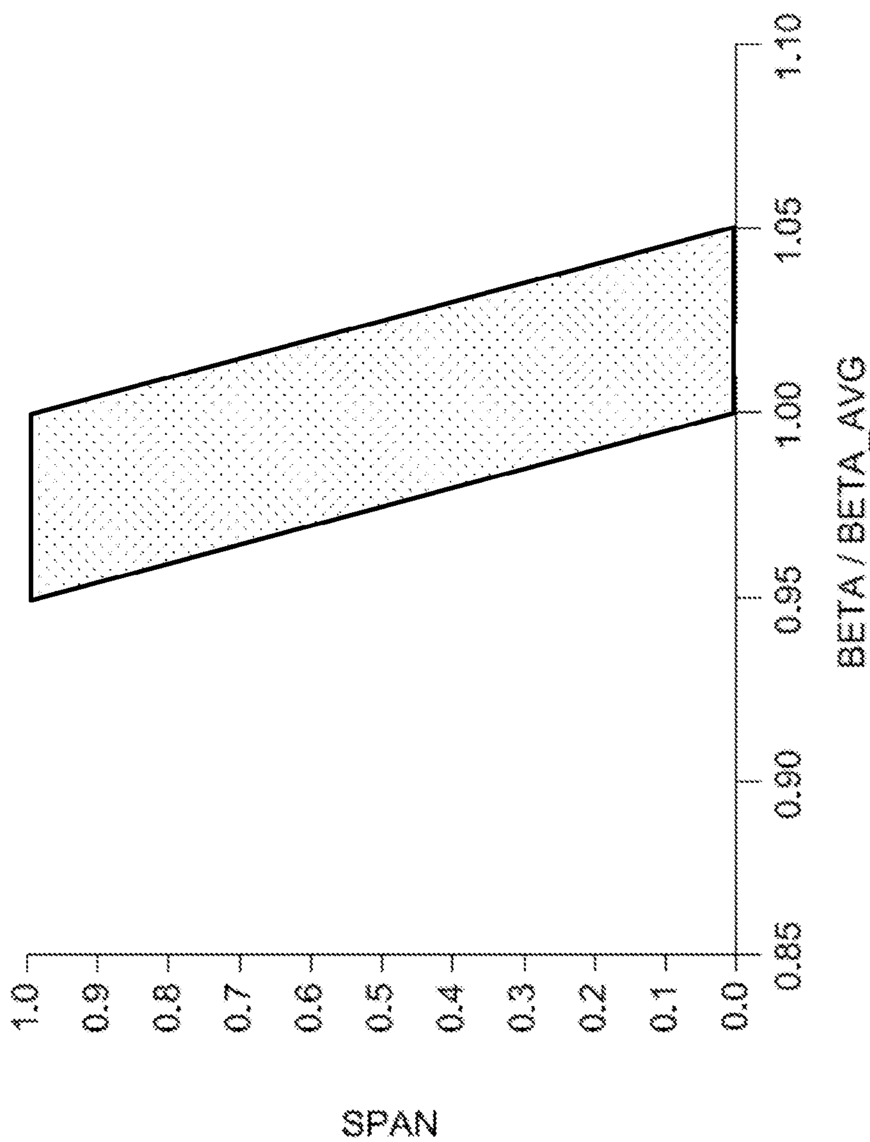
SPAN
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.85
0.90
0.95
1.00
1.05
1.10
BETA / BETA_AVG

FIG. 3

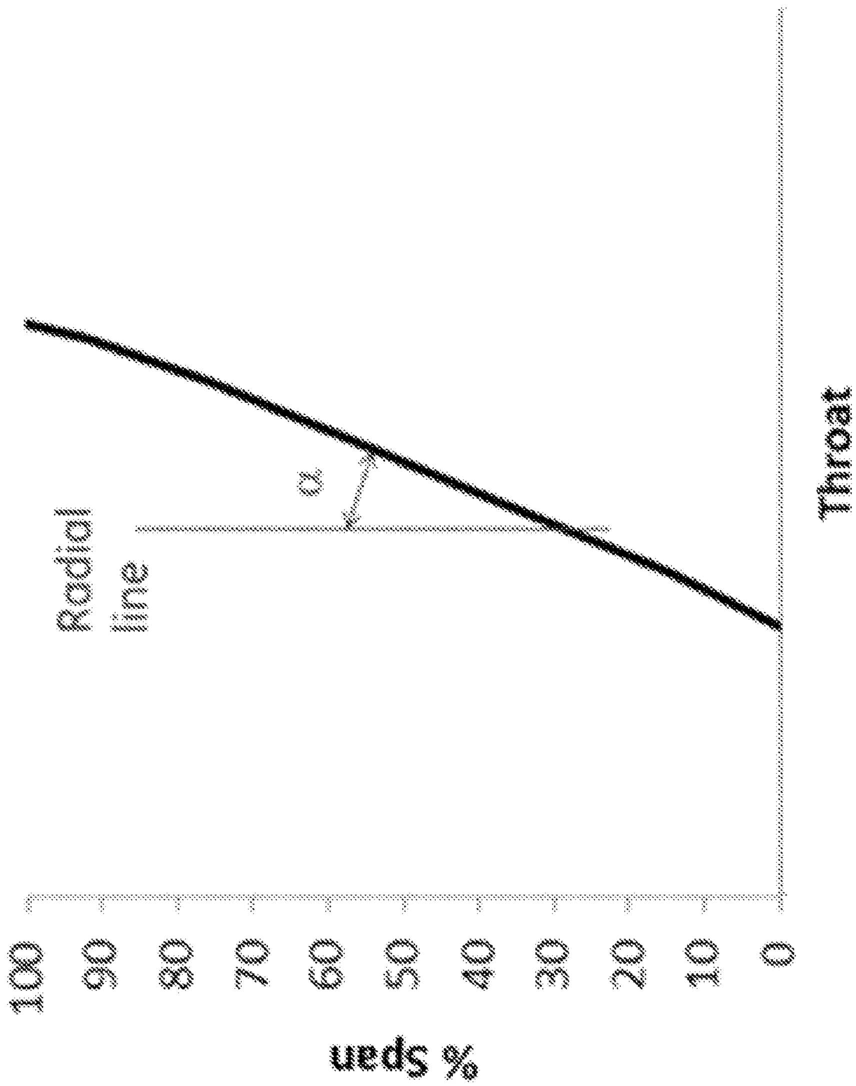

FIG. 4

TURBINE OF A TURBOMACHINE

BACKGROUND OF THE INVENTION

The subject matter disclosed herein relates to a turbomachine and, more particularly, to a turbomachine having airfoil throat distributions producing a tip strong pressure profile in a fluid flow.

A turbomachine, such as a gas turbine engine, may include a compressor, a combustor and a turbine. The compressor compresses inlet gas and the combustor combusts the compressed inlet gas along with fuel to produce high temperature fluids. Those high temperature fluids are directed to the turbine where the energy of the high temperature fluids is converted into mechanical energy that can be used to generate power and/or electricity. The turbine is formed to define an annular pathway through which the high temperature fluids pass.

The energy conversion in the turbine may be achieved by a series of blade and nozzle stages disposed along the pathway. Aerodynamic properties in a root region of the last stage are typically limited when a radial throat distribution is chosen to achieve a flat turbine exit profile. Specifically, root convergence may be relatively low and the performance in the root region may suffer as a result.

BRIEF DESCRIPTION OF THE INVENTION

According to one aspect of the invention, a turbine of a turbomachine is provided and includes opposing endwalls defining a pathway for a fluid flow and a plurality of interleaved blade stages and nozzle stages arranged axially along the pathway. The plurality of the blade stages includes a last blade stage at a downstream end of the pathway and a next-to-last blade stage upstream from the last blade stage. The plurality of the nozzle stages includes a last nozzle stage between the last blade stage and the next-to-last blade stage and a next-to-last nozzle stage upstream from the next-to-last blade stage. At least one of the next-to-last blade stage and the next-to-last nozzle stage includes aerodynamic elements configured to interact with the fluid flow and to define a throat distribution producing a tip strong pressure profile in the fluid flow.

According to another aspect of the invention, a turbine of a turbomachine is provided and includes opposing endwalls defining a pathway for a fluid flow and a plurality of interleaved blade stages and nozzle stages arranged axially along the pathway. The plurality of the blade stages includes a last blade stage at a downstream end of the pathway and a next-to-last blade stage upstream from the last blade stage. The plurality of the nozzle stages includes a last nozzle stage between the last blade stage and the next-to-last blade stage and a next-to-last nozzle stage upstream from the next-to-last blade stage. The next-to-last blade stage includes aerodynamic elements configured to interact with the fluid flow and to define a throat distribution producing a tip strong pressure profile in the fluid flow.

According to another aspect of the invention, a turbomachine is provided and includes a compressor to compress inlet gas to produce compressed inlet gas, a combustor to combust the compressed inlet gas along with fuel to produce a fluid flow and a turbine receptive of the fluid flow and comprising opposing endwalls defining a pathway for the fluid flow and a plurality of interleaved blade stages and nozzle stages arranged axially along the pathway. The plurality of the blade stages includes a next-to-last blade stage and a last blade stage sequentially disposed along the pathway. The plurality of the nozzle stages includes a next-to-last nozzle stage and a last nozzle stage sequentially disposed along the pathway. At least one of the next-to-last blade stage and the next-to-last nozzle stage includes aerodynamic elements configured to interact with the fluid flow and to define a throat distribution producing a tip strong pressure profile in the fluid flow.

According to yet another aspect of the invention, a turbine of a turbomachine is provided and includes opposing endwalls defining a pathway for a fluid flow and a plurality of interleaved blade stages and nozzle stages arranged axially along the pathway. The plurality of the blade stages include a last blade stage at a downstream end of the pathway and a next-to-last blade stage upstream from the last blade stage, and the plurality of the nozzle stages include a last nozzle stage between the last blade stage and the next-to-last blade stage and a next-to-last nozzle stage upstream from the next-to-last blade stage. The last blade stage and the last nozzle stage include aerodynamic elements configured to achieve a substantially flat exit pressure profile.

These and other advantages and features will become more apparent from the following description taken in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The subject matter, which is regarded as the invention, is particularly pointed out and distinctly claimed in the claims at the conclusion of the specification. The foregoing and other features, and advantages of the invention are apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. **1** is a schematic diagram of a gas turbine engine;

FIG. **2** is a side of an interior of a turbine of the gas turbine engine of FIG. **1**;

FIG. **3** is a graphical illustration of a non-dimensional relative exit angle distribution range in accordance with embodiments; and

FIG. **4** is a graphical illustration of the throat distribution of next-to-last or last blade or nozzle stages according to exemplary embodiments of the present subject matter.

The detailed description explains embodiments of the invention, together with advantages and features, by way of example with reference to the drawings.

DETAILED DESCRIPTION OF THE INVENTION

With reference to FIGS. **1** and **2** and, in accordance with aspects of the invention, a turbomachine **10** is provided as, for example, a gas turbine engine **11**. As such, the turbomachine **10** may include a compressor **12**, a combustor **13** and a turbine **14**. The compressor **12** compresses inlet gas and the combustor **13** combusts the compressed inlet gas along with fuel to produce high temperature fluids. Those high temperature fluids are directed to the turbine **14** where the energy of the high temperature fluids is converted into mechanical energy that can be used to generate power and/or electricity.

The turbine **14** includes a first annular endwall **201** and a second annular endwall **202**, which is disposed about the first annular endwall **201** to define an annular pathway **203**. The annular pathway **203** extends from an upstream section thereof, which is proximate to the combustor **13**, to a downstream section thereof, which is remote from the combustor **13**. That is, the high temperature fluids are output from the combustor **13** and pass through the turbine **14** along the pathway **203** from the upstream section to the downstream section.

At a portion **20** of the turbine, the turbine **14** includes a plurality of interleaved blade and nozzle stages. The blade stages may include last blade stage **21**, which may be disposed proximate to an axially downstream end of the pathway **203**, next-to-last blade stage **23**, which may be disposed upstream from the last blade stage **21**, and one or more upstream blade stages **25**, which may be disposed upstream from the next-to-last blade stage **23**. The nozzles stages may include last nozzle stage **22**, which is disposed axially between the last blade stage **21** and the next-to-last blade stage **23**, next-to-last nozzle stage **24**, which may be disposed upstream from the next-to-last blade stage **23**, and one or more upstream nozzles stages **26**, which may be disposed upstream from the one or more upstream blade stages **25**.

The last blade stage **21** includes an annular array of a first type of aerodynamic elements (hereinafter referred to as "blades"), which are provided such that each blade is extendible across the pathway **203** and between the first and second endwalls **201** and **202**. The next-to-last blade stage **23** and the one or more upstream blade stages **25** are similarly configured. The last nozzle stage **22** includes an annular array of a second type of aerodynamic elements (hereinafter referred to as "nozzles"), which are provided such that each nozzle is extendible across the pathway **203** and between the first and second endwalls **201** and **202**. The next-to-last nozzle stage **24** and the one or more upstream nozzle stages **26** are similarly configured.

Each of the blades and the nozzles may have an airfoil shape with a leading edge, a trailing edge that opposes the leading edge, a pressure side extending between the leading edge and the trailing edge and a suction side opposing the pressure side and extending between the leading edge and the trailing edge. Each of the blades and nozzles may be disposed such that a pressure side of any one of the blades and nozzles faces a suction side of an adjacent one of the blades and nozzles, respectively, within a given stage. With this configuration, as the high temperature fluids flow through the pathway **203**, the high temperature fluids aerodynamically interact with the blades and nozzles and are forced to flow with an angular momentum relative to a centerline of the turbine **14** that causes the last blade stage **21**, the next-to-last blade stage **23** and the one or more upstream blade stages **25** to rotate about the centerline.

In general, a throat is defined as a narrowest region between adjacent nozzles or blades in a given stage. A radial throat distribution, then, is representative of throat measurements of adjacent nozzles or blades in a given stage at various span (i.e., radial) locations. Normally, aerodynamic properties in root regions of blades of the last blade stage **21**, which are proximate to the first endwall **201**, are typically limited when a radial throat distribution is chosen to achieve a flat turbine exit profile. In particular, root convergence may be relatively low and blade stage performance in the root region may suffer as a result. However, in accordance with aspect, inlet profiles to the last blade stage **21** can be biased to be tip strong such that a design space of the blades at the last blade stage **21** is opened to achieve a substantially flat exit pressure profile without the expense of poor root region aerodynamics.

This is achieved by choosing radial throat distributions of adjacent aerodynamic elements of at least one of the next-to-last blade stage **23** and the next-to-last nozzle stage **24** such that radial work distribution produces a tip strong total pressure profile exiting the next-to-last blade stage **23** and the next-to-last nozzle stage **24**. In doing so, the fluid flow is conditioned by the next-to-last blade stage **23** and the next-to-last nozzle stage **24** as the fluid flow continues to proceed toward the last blade stage **21** and the last nozzle stage **22**. Although it is to be understood that the choosing of the radial throat distributions can relate to the next-to-last blade stage **23** and/or the next-to-last nozzle stage **24**, for purposes of clarity and brevity the choosing of the radial throat distribution of only the next-to-last blade stage **23** will be described in detail.

As shown in FIG. **3**, the radial throat distribution is a circumferentially averaged profile that, when chosen as described herein, exhibits a non-dimensional, relative exit angle distribution ranging from between 1.00 and 1.05 at or proximate to the first endwall **201** to between 0.95 and 1.00 at or proximate to the second endwall **202**. This relatively strong forced vortexing scheme opens the design space of both the last nozzle stage **22** and the last blade stage **21** where a flat turbine exit total pressure profile to the diffuser is targeted to thereby improve the stage performance of at least the last blade stage **21** for a given flat exit total pressure distribution target. The flat inlet profile to a diffuser downstream from the turbine **14** may be chosen for diffuser recovery and minimal peak velocity to heat recovery steam generator (HRSG) systems.

In accordance with embodiments of the invention, adjacent nozzles of the last nozzle stage **22** may be arranged to exhibit the following exemplary non-dimensional characteristics:

Span	Throat
100	1.29 ± 10%
92.2	1.26 ± 10%
76.0	1.16 ± 10%
58.4	1.04 ± 10%
38.6	0.90 ± 10%
14.8	0.73 ± 10%
0.0	0.61 ± 10%

In accordance with embodiments of the invention, adjacent blades of the last blade stage **21** may be arranged to exhibit the following exemplary non-dimensional characteristics:

Span	Throat
100	1.13 ± 10%
91.9	1.12 ± 10%
75.7	1.09 ± 10%
58.3	1.06 ± 10%
38.7	0.98 ± 10%
15.1	0.85 ± 10% width
0.0	0.76 ± 10% width

In accordance with embodiments of the invention, adjacent nozzles of the next-to-last nozzle stage **24** may be arranged to exhibit the following exemplary non-dimensional characteristics:

Span	Throat
100	1.20 ± 10%
90.0	1.16 ± 10%
70.0	1.08 ± 10%
50.0	1.00 ± 10%
30.0	0.92 ± 10%
10.0	0.84 ± 10%
0.0	0.81 ± 10%

In accordance with embodiments of the invention, adjacent blades of the next-to-last blade stage **23** may be arranged to exhibit the following exemplary non-dimensional characteristics:

Span	Throat
100	1.18 ± 10%
90.0	1.15 ± 10%
70.0	1.08 ± 10%
50.0	1.01 ± 10%
30.0	0.93 ± 10%
10.0	0.85 ± 10%
0.0	0.80 ± 10%

As illustrated in FIG. **4**, the foregoing characteristics of adjacent blades or nozzles of next-to-last and last blade or nozzle stages may be represented graphically as a plot of throat versus span. As shown in FIG. **4**, in exemplary embodiments of the present subject matter, the throat distribution increases along the entire span of the blades or nozzles.

While the invention has been described in detail in connection with only a limited number of embodiments, it should be readily understood that the invention is not limited to such disclosed embodiments. Rather, the invention can be modified to incorporate any number of variations, alterations, substitutions or equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the invention. Additionally, while various embodiments of the invention have been described, it is to be understood that aspects of the invention may include only some of the described embodiments. Accordingly, the invention is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

The invention claimed is:

1. A turbine of a turbomachine, comprising:

opposing first and second endwalls defining a pathway for a fluid flow; and

a plurality of interleaved blade stages and nozzle stages arranged axially along the pathway,

the plurality of the blade stages including a last blade stage at a downstream end of the pathway and a next-to-last blade stage upstream from the last blade stage,

the plurality of the nozzle stages including a last nozzle stage between the last blade stage and the next-to-last blade stage and a next-to-last nozzle stage upstream from the next-to-last blade stage, and

at least one of the next-to-last blade stage and the next-to-last nozzle stage including aerodynamic elements configured to interact with the fluid flow and to define a throat distribution as a radial throat distribution that is a circumferentially averaged profile that exhibits a non-dimensional relative exit angle distribution ranging from between 1.00 and 1.05 at the first endwall to between 0.95 and 1.00 at the second endwall,

wherein adjacent blades of the next-to-last blade stage are arranged such that the throat distribution increases along an entire span of the blades and adjacent nozzles of the next-to-last nozzle stage are arranged such that the throat distribution increases along an entire span of the nozzles.

2. The turbine according to claim **1**, wherein the fluid flow comprises a flow of high temperature fluids produced by combustion.

3. The turbine according to claim **1**, wherein each blade stage of the plurality of the blade stages comprises an annular array of blades that extend through the pathway between the opposing first and second endwalls.

4. The turbine according to claim **1**, wherein each nozzle stage of the plurality of the nozzle stages comprises an annular array of nozzles that extend through the pathway between the opposing first and second endwalls.

5. The turbine according to claim **1**, wherein the aerodynamic elements of at least the next-to-last blade stage comprise adjacent aerodynamic elements.

6. The turbine according to claim **1**, wherein at least one of the last blade stage and the last nozzle stage includes adjacent aerodynamic elements.

7. A turbine of a turbomachine, comprising:

opposing first and second endwalls defining a pathway for a fluid flow; and

a plurality of interleaved blade stages and nozzle stages arranged axially along the pathway,

the plurality of the blade stages including a last blade stage at a downstream end of the pathway and a next-to-last blade stage upstream from the last blade stage,

the plurality of the nozzle stages including a last nozzle stage between the last blade stage and the next-to-last blade stage and a next-to-last nozzle stage upstream from the next-to-last blade stage, and

the next-to-last blade stage including aerodynamic elements configured to interact with the fluid flow and to define a throat distribution as a radial throat distribution that is a circumferentially averaged profile that exhibits a non-dimensional relative exit angle distribution ranging from between 1.00 and 1.05 at the first endwall to between 0.95 and 1.00 at the second endwall,

wherein adjacent blades of the next-to-last blade stage are arranged such that the throat distribution increases along an entire span of the blades.

8. The turbine according to claim **7**, wherein the fluid flow comprises a flow of high temperature fluids produced by combustion.

9. The turbine according to claim **7**, wherein each blade stage of the plurality of the blade stages comprises an annular array of blades that extend through the pathway between the opposing first and second endwalls.

10. The turbine according to claim **7**, wherein each nozzle stage of the plurality of the nozzle stages comprises an annular array of nozzles that extend through the pathway between the opposing first and second endwalls.

11. The turbine according to claim **7**, wherein the aerodynamic elements of at least the next-to-last blade stage comprise adjacent aerodynamic elements.

12. The turbine according to claim **7**, wherein at least one of the last blade stage and the last nozzle stage includes adjacent aerodynamic elements.

13. A turbomachine, comprising:

a compressor to compress inlet gas to produce compressed inlet gas;

a combustor to combust the compressed inlet gas along with fuel to produce a fluid flow; and

a turbine receptive of the fluid flow and comprising opposing first and second endwalls defining a pathway for the fluid flow and a plurality of interleaved blade stages and nozzle stages arranged axially along the pathway,

the plurality of the blade stages including a next-to-last blade stage and a last blade stage sequentially disposed along the pathway,

the plurality of the nozzle stages including a next-to-last nozzle stage and a last nozzle stage sequentially disposed along the pathway, and

at least one of the next-to-last blade stage and the next-to-last nozzle stage including aerodynamic elements configured to interact with the fluid flow and to define a throat distribution as a radial throat distribution that is a circumferentially averaged profile that exhibits a non-dimensional relative exit angle distribution ranging from between 1.00 and 1.05 at the first endwall to between 0.95 and 1.00 at the second endwall,

wherein adjacent blades of the next-to-last blade stage are arranged such that the throat distribution increases along an entire span of the blades and adjacent nozzles of the next-to-last nozzle stage are arranged such that the throat distribution increases along an entire span of the nozzles.

14. The turbomachine according to claim **13**, wherein the fluid flow comprises a flow of high temperature fluids produced by combustion within the combustor.

15. The turbomachine according to claim **13**, wherein each blade stage of the plurality of the blade stages comprises an annular array of blades that extend through the pathway between the opposing first and second endwalls.

16. The turbomachine according to claim **13**, wherein each nozzle stage of the plurality of the nozzle stages comprises an annular array of nozzles that extend through the pathway between the opposing first and second endwalls.

17. The turbomachine according to claim **13**, wherein the aerodynamic elements of at least the next-to-last blade stage comprise adjacent aerodynamic elements.

18. The turbomachine according to claim **13**, wherein at least one of the last blade stage and the last nozzle stage includes adjacent aerodynamic elements.

19. A turbine of a turbomachine, comprising:

opposing first and second endwalls defining a pathway for a fluid flow; and

a plurality of interleaved blade stages and nozzle stages arranged axially along the pathway,

the plurality of the blade stages including a last blade stage at a downstream end of the pathway and a next-to-last blade stage upstream from the last blade stage,

the plurality of the nozzle stages including a last nozzle stage between the last blade stage and the next-to-last blade stage and a next-to-last nozzle stage upstream from the next-to-last blade stage, and

the last blade stage and the last nozzle stage including aerodynamic elements configured to define a throat distribution as a radial throat distribution that is a circumferentially averaged profile that exhibits a non-dimensional relative exit angle distribution ranging from between 1.00 and 1.05 at the first endwall to between 0.95 and 1.00 at the second endwall,

wherein adjacent blades of the last blade stage are arranged such that the throat distribution increases along an entire span of the blades and adjacent nozzles of the last nozzle stage are arranged such that the throat distribution increases along an entire span of the nozzles.

* * * * *